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PORTSIM 5: Modeling from a Seaport Level

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Abstract—This paper describes PORTSIM 5, a discrete-event seaport simulation model. Specifically, we discuss the developmental efforts and existing system limitations that have led up to the current efforts being undertaken by the Military Traffic Management Command Transportation Engineering Agency and Argonne National Laboratory. PORTSIM 5 builds on the knowledge and expertise gained from two preceding port simulation models, PORTSIM 4.3 and CPORTS 1.4, and incorporates a set of rules and conventions to address the issue of resource competition. We will provide a brief description of the preceding models and illustrate their individual shortcomings. The paper will go on to describe PORTSIM 5 and the three main areas it models, port areas of operation, port processes, and port resources. Port resource allocation methods will also be addressed. In PORTSIM 5, the graphical user interface (GUI) has been decoupled from the simulation. Here we provide a short section on the GUI and illustrate with sample screens and output. Finally, future enhancements are suggested.

Keywords—Port, Seaport, Modeling, Simulation, Logistics, Transportation, Military, Mobility, Infrastructure.

1. INTRODUCTION

Accurate, dependable computer modeling of seaport operations has been a priority of the military logistics community in recent years. Because an ability to simulate seaport operations provides military logistics analysts with the detailed information necessary to plan efficient deployments, a high level of effort has been dedicated to simulating flows of cargo and equipment through both ports of embarkation and ports of debarkation. Until now, the tasks of modeling these movements have been undertaken independently, with Argonne National Laboratory (ANL) developing the port of embarkation (POE) model, PORTSIM, and the Virginia Modeling, Analysis and Simulation Center (VMASC) developing the port of debarkation (POD) model, CPORTS.

The POE and POD modeling efforts have focused on simulating one-way traffic through a port, modeling from an isolated perspective. There was a conscious assumption made to model the

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seaport as a dedicated system, allocating all available resources to the selected operation, either POE or POD. While this modeling approach provided an accurate analysis, it soon became apparent that the core of the port operations problem lay in modeling port processes from a bidirectional port-level rather than the previous one-way assumption. By implementing a port-level design, a more accurate representation of resource and infrastructure constraints could be achieved. The level of detail acquired previously by focusing on each type of operation, either POE or POD, became an invaluable foundation for the next phase of development, the port-level model. PORTSIM 5 is being developed at ANL as such a model.

The challenge of modeling concurrent port processes lies in dealing with the issue of resource constraints. Competition for and availability of common resources can impact throughput dramatically, and decreases in throughput can have a substantive negative impact on a deployment mission. While PORTSIM 4.3 and CPORTS 1.4 address resource constraints from their individual perspectives, PORTSIM 5 addresses those challenges by integrating embarkation and debarkation processes and implementing a set of rules and conventions that assign precedence and priorities to competing resources. The result is a more accurate port simulation model that affords better overall data on throughput capabilities.

This paper describes the evolution and subsequent shortcomings of the seaport modeling efforts undertaken by ANL and VMASC and the current challenges being met at Argonne in developing a port-level model that accurately simulates the system and measures throughput while addressing the resource constraints that tax the system. Finally, we take a look at high-level architecture (HLA) requirements and future enhancements that advance beyond port infrastructure and processes to exogenous variables that can directly impact the simulation.

2. PORTSIM 4—MODELING THE PORT OF EMBARKATION (POE)

PORTSIM began as an Argonne proposal to the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) in the fall of 1993 as a response to the military's growing need to simulate movement through seaports. Equation-based programs were already in use letting analysts calculate throughput. One such program is the port operational performance simulator (POPS)—"a deterministic throughput calculator computer program that allows seaport analysts to quickly determine seaport throughput capabilities on an aggregate level" [1]. Both Argonne and the MTMCTEA saw a need for a more detailed model that relied on discrete-event simulation theory. Argonne began working on such a model in 1994 and continued to revise and refine the model based on MTMCTEA requirements and guidance through the fall of 2001.

PORTSIM 4 continues to be supported by Argonne, and Version 4.3 is currently in use at the MTMCTEA. PORTSIM 4.3 is a discrete-event simulation that facilitates the analysis of movement of military-unit equipment through seaports worldwide and allows for detailed infrastructure analyses. It assists planners in comparing and selecting ports by determining their throughput capabilities and their utilization of critical resources [2]. It is primarily used to determine a port's ability to deploy units of various sizes—for example, the length of time it takes to deploy an armored cavalry division through the port, given a specified allocation of port resources. It can also be used to identify ports for which additional infrastructure (newly constructed or leased from the port) can speed the process of deployment. For example, if additional rail spurs are added for offloading, the force may close ten hours earlier. PORTSIM 4.3 has recently been used to develop contingency deployment plans for classified real-world scenarios.

The POE model looks at reception, staging, and ship loading. Reception models the means and resources required to move cargo through a port's entry points, including gates, which accept highway transports, and interchange yards, which accept railway transports. Staging models the methods and resources needed to inspect cargo and queue it for ship loading. Ship loading models the methods and resources required to call forward cargo to a berth and load it onto a ship.

While used successfully and extensively for port throughput analyses (its original purpose), PORTSIM 4.3 suffers from several shortcomings that hamper the military analyst's ability to analyze force deployments. Though PORTSIM models individual pieces of cargo and can provide detailed information about that cargo, the closure profiles can only be analyzed for the entire force. Closure profiles for subsets of the force cannot be taken literally due to the model's shortcomings. Among these shortcomings are the following.

- Lack of unit integrity for ship loading—equipment may be spread across multiple ships without planning to account for the ships final destinations.
- Equipment is loaded on a first-in, first-out basis without regard for the required delivery date at the destination.
- Port resource and infrastructure utilization information is captured at the beginning of each simulated hour rather than on a continual basis leading to inaccurate representation of the actual utilization.
- Not all port resource and infrastructure utilization information is saved at the end of a simulation run.
- Helicopter processes are not sufficiently detailed. In 4.3 these processes were added primarily so that the model could account for space consumption on the ships.
- The graphical user interface and the simulation are tightly coupled resulting in long run times. This can limit the number of "what-if" cases that the analyst can run when a quick turn-around analysis is required.
- The set of reports and graphs is fixed and does not provide the capability to view results for user-defined subsets of the data. The saved output cannot be processed to provide this information either.

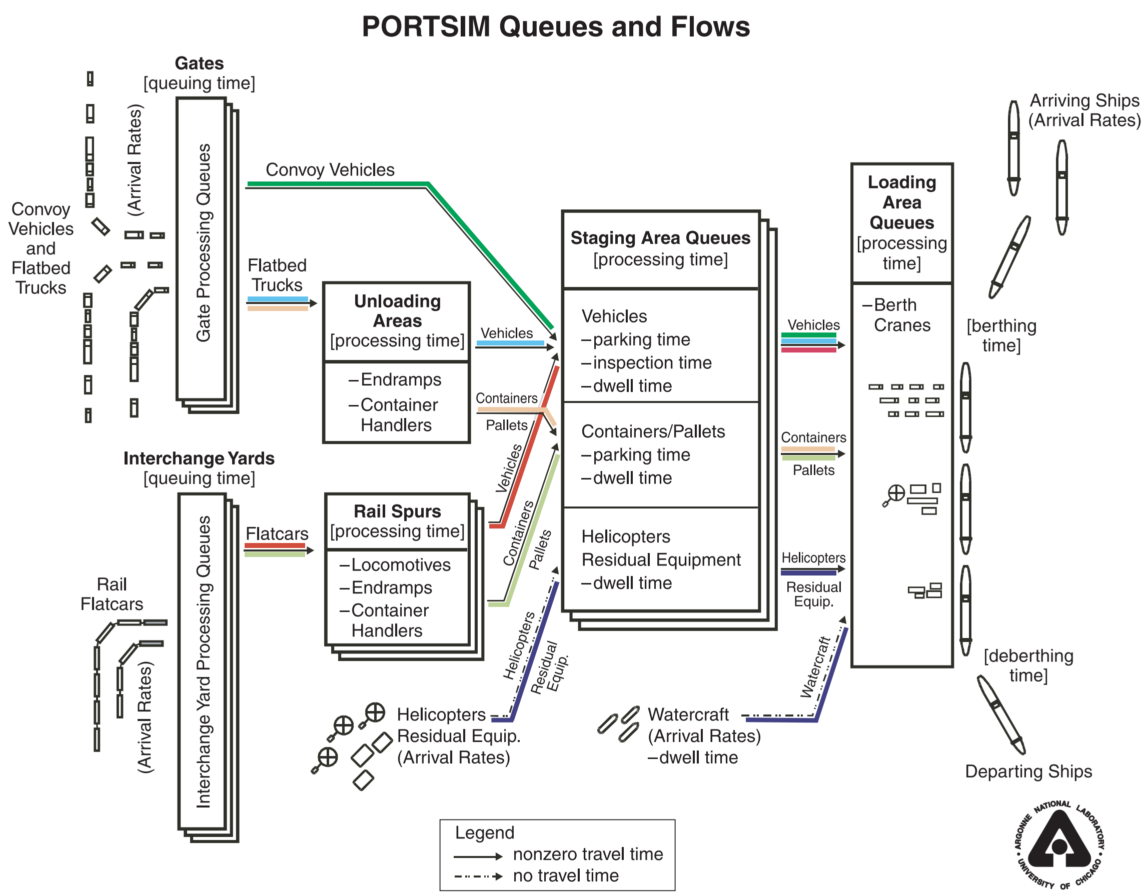

Figure 1. PORTSIM 4.3 models flows of cargo through ports of embarkation.

- The representation of the port requires that all port infrastructure be physically located within the port boundaries. For large U.S. ports, this can be a reasonable assumption. However, for smaller foreign ports, this may not be accurate and the model provides no means to simulate port areas, such as staging, outside the boundaries of the port.
- Travel times between port areas were specified simply as averages rather than individual travel times for each area to area route.

Figure 1 depicts the flow of cargo through a POE.

3. CPORTS 1.4—MODELING THE PORT OF DEBARKATION (POD)

The CPORTS 1.4 POD model follows cargo as it arrives on a ship at a berth and performs an analysis similar to that of a POE model, but looks at berth, anchorage, staging, loading area, call forward area, gate area, and interchange yard area objects. The POD model tracks cargo items as they are offloaded from a ship and make their way through a port, finally exiting the port either under their own power (wheeled vehicles, helicopters, and watercraft) or upon highway or rail transport (tracked vehicles, containers, etc.). A major contribution to the port modeling process in CPORTS 1.4 is the ability to reconfigure the port during the simulation. CPORTS 1.4 supports programmed events that allow the user to specify changes in data at specific times during the simulation. Many scenario parameters can be affected by these events, including process times, port area capacities and routing. Currently, these programmed events would be calculated externally and specified in the scenario input file. The CPORTS model also has been extensively used in the analysis of and planning for military deployments.

VMASC was contracted by MTMCTEA to develop a port of debarkation (POD) version of the PORTSIM model. Among their requirements was the need to address the shortcomings that were present in the POE version of PORTSIM. The result of their efforts is CPORTS 1.4. CPORTS 1.4 successfully overcame the issues of unit integrity, ship-loading order, helicopter processing, GUI-simulation coupling, reporting and graphing, port reconfiguration, and travel time specification. However, the issue of port resource and infrastructure utilization data remains. To increase the performance of the simulation, a conscious decision not to capture this data was made. Rather, the data could be inferred from the information stored at the end of the simulation run. However, wait times for resources and infrastructure could be lost in this process. In addition, new shortcomings were introduced in CPORTS 1.4. Among these were the following.

- Virtual port areas are defined for which the accounting of space utilization is not totally complete.
- Only one anchorage is supported.
- For each type of helicopter processing area, only one type is supported.
- Only a single staging area/gate association can be made (i.e., exiting the port from a specific staging area requires the use of only one specific gate—no optional routing is allowed).
- The GUI is cumbersome to use. (Note: the GUI was developed with the understanding that it would be completely rewritten.)

Figure 2 depicts the flow of cargo through a POD.

In addition to the shortcomings of each model listed above, useful enhancements were made individually to the models as their development continued in parallel to address the needs of the different user communities. Most important among these are the ability to change process times and various other model parameters during a CPORTS simulation run (data specified prior to run time) and the greater flexibility PORTSIM 4.3 offers in the assigning of ships to berths.

These two models could be used independently to analyze a single port that serves both embarking and debarking forces provided that there was no overlap in time frames as information

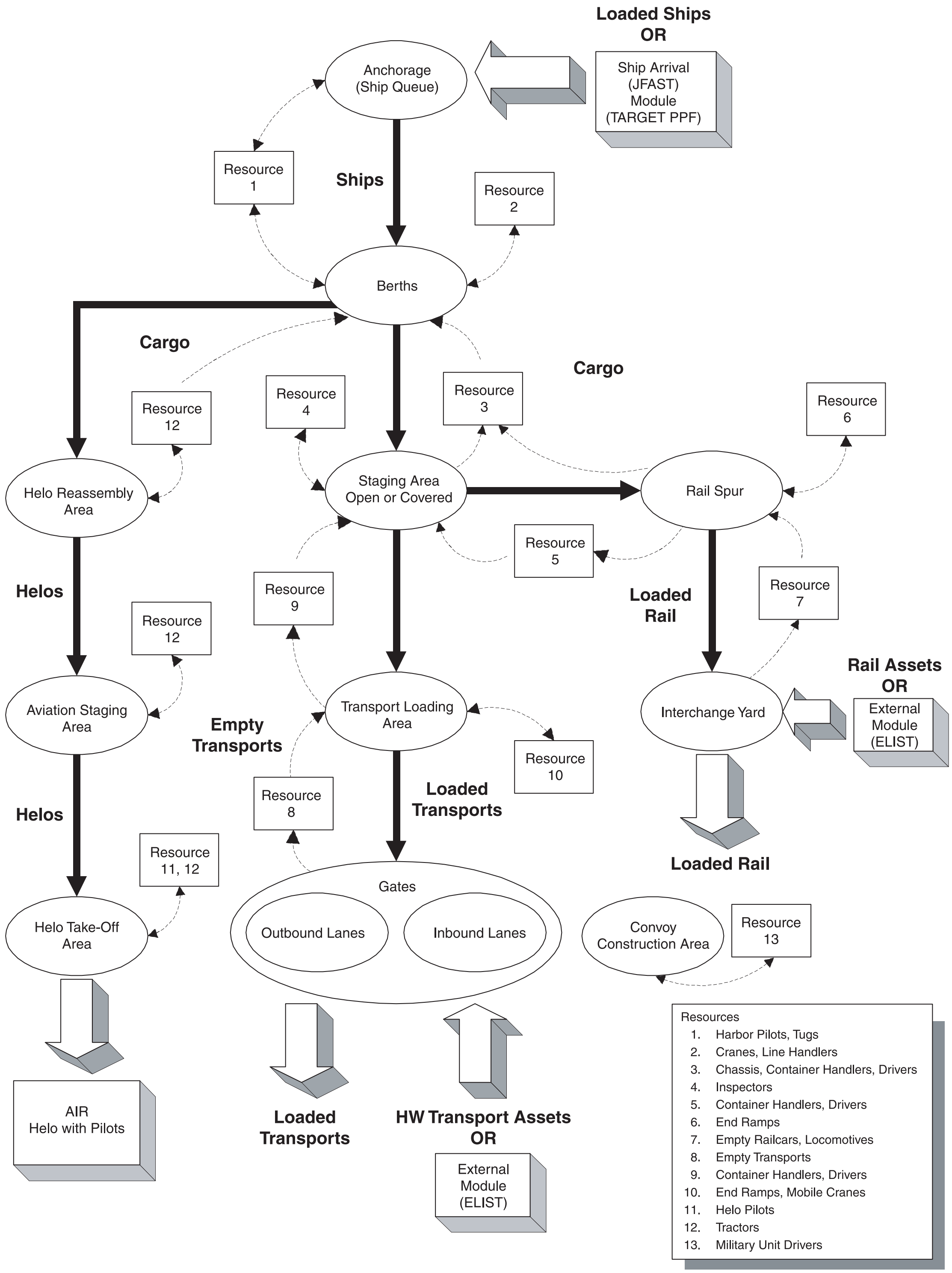

Figure 2. CPORTS models flows of cargo through port of debarkation [2].

cannot be shared between the two models. Even in the best of situations, there would be inconsistencies in the level of information that could be reported from the simulations. A decision was made to merge the two models in an effort to provide the analysts with a port model that could simulate embarking and debarking forces in a common environment and capture the subtle implications of port resources and infrastructure sharing.

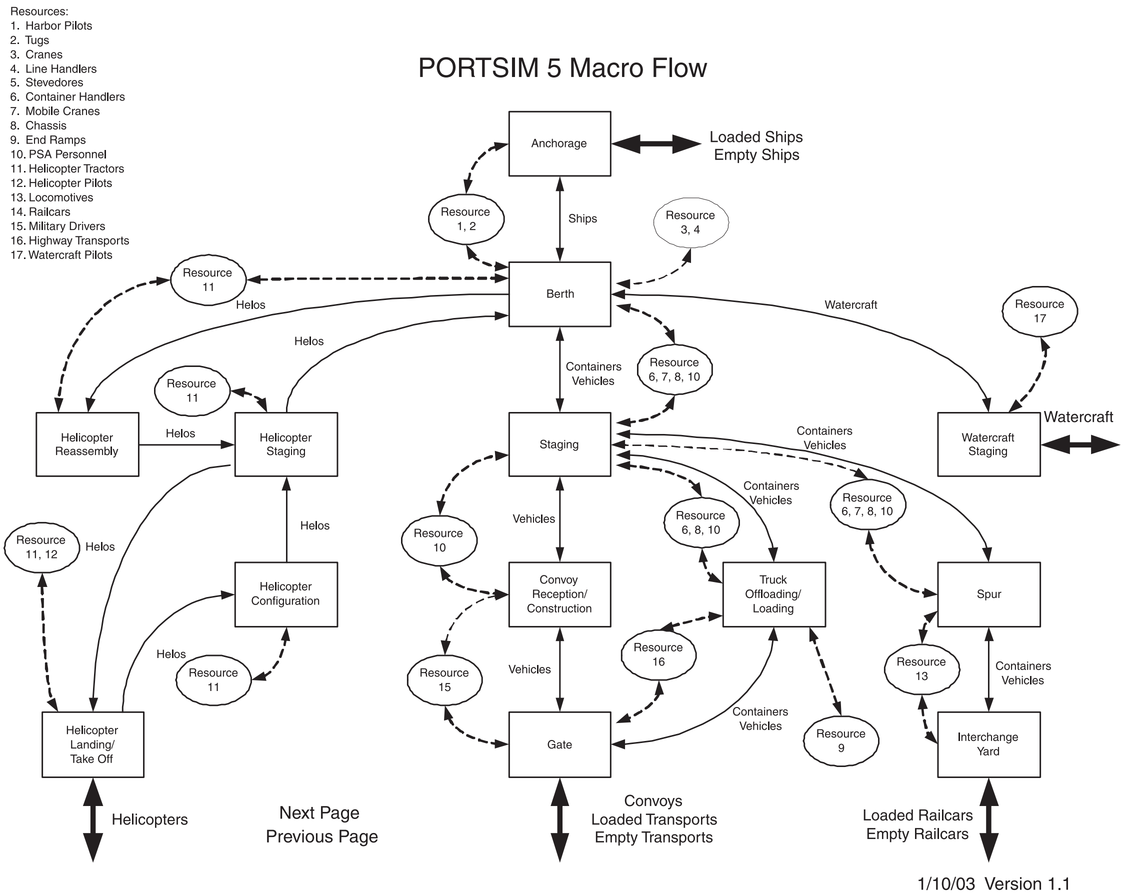

Figure 3. PORTSIM 5 macro flow.

While the POE and POD models are an invaluable foundation for seaport simulation, there still exists a need to model a seaport as one entity, rather than as two separate components, while taking advantage of the work already done on the POE and POD sides. Work on PORTSIM 5 began in earnest at Argonne in the fall of 2001 under direct guidance from the MTMCTEA, and its development is ongoing. The beta version of PORTSIM 5 is scheduled for delivery on April 30, 2003. The challenge is to make full use of the knowledge gained in developing the component pieces while merging them into a model that will accurately simulate real-life seaport trafficking. In looking at the problem from a port perspective, the model will simulate simultaneous inbound and outbound traffic for the first time.

PORTSIM 5 blends the features of CPORTS 1.4 and PORTSIM 4.3 into a single model that alleviates the shortcomings of the individual models, applies the enhancements to the opposite model, and allows the user to simulate POD-only, POE-only, and concurrent operations.

Figure 3 depicts cargo flow through a combined POE/POD port.

PORTSIM 5 is designed to model the significant areas of operation, processes, and resources at a port. It is being implemented in MODSIM III, an object-oriented simulation language developed by CACI. The model uses the MTMCTEA GIS ACCESS database for its source of port infrastructure.

4.1. Areas of Operation

Each port can have six different types of physical port areas: anchorages, berths, spurs, gates, interchange yards, and staging areas. The staging areas are divided into a number of virtual areas: convoy processing, truck processing, container staging, vehicle staging, helicopter landing, helicopter processing, helicopter landing and takeoff, and watercraft. These virtual areas are treated as rectangular areas of a specified size and consume space within the staging area in which they are located. Though the source of data is a GIS database, no spatial data on the port areas is extracted.

The equipment that is processed by the port is defined by the time phased force deployment data (TPFDD). A TPFDD is the joint operation planning and execution system database portion of an operation plan; it contains time-phased force data, non-unit-related cargo and personnel data, and movement data for the operation plan, including:

(a) in-place units;
(b) units to be deployed to support the operation plan with a priority indicating the desired sequence for their arrival at the port of debarkation;
(c) routing of forces to be deployed;
(d) movement data associated with deploying forces;
(e) estimates of nonunit-related cargo and personnel movements to be conducted concurrently with the deployment of forces;
(f) estimate of transportation requirements that must be fulfilled by common-user lift resources as well as those requirements that can be fulfilled by assigned or attached transportation resources [4].

A TPFDD is "expanded" to Level 6 detail (individual cargo items) by software developed at MTMCTEA [5]. These records contain the data on the type of cargo, the physical size and weight of each item, when they are scheduled to arrive at the port, the transport on which they arrive, if not self-propelled, and when they are required to be at their final destination and the ship on/from which they are to be loaded/offloaded.

The port area set object hierarchy is provided in Figure 4.

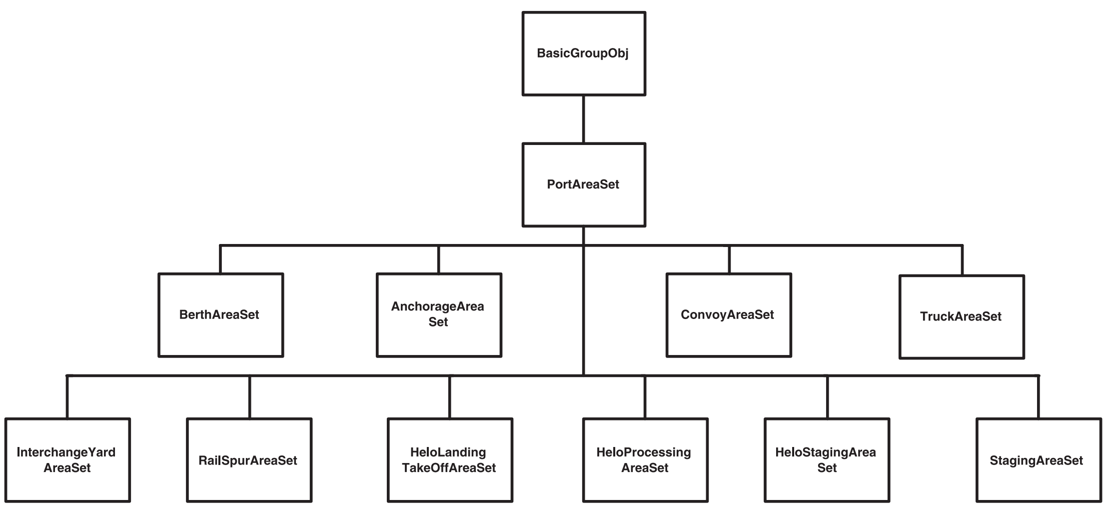

Figure 4. Port area set object hierarchy.

For each distinct type of port area, there is one port area set object instantiated. These objects contain the attributes that are common across all port areas of the same type. The process time distribution associated with a specific process is used by all port areas of the appropriate type. For example, the vehicle staging inspection time, stored in the StagingAreaSet object, will be referenced by all defined vehicle staging areas at the port. The model does not allow for area-specific process times. These objects also contain a list of all defined port areas of the appropriate type. The logic that determines which of the physical areas will be accessed during the simulation is contained in these objects.

Figure 5 depicts the port area objects that model a specific physical area in the port.

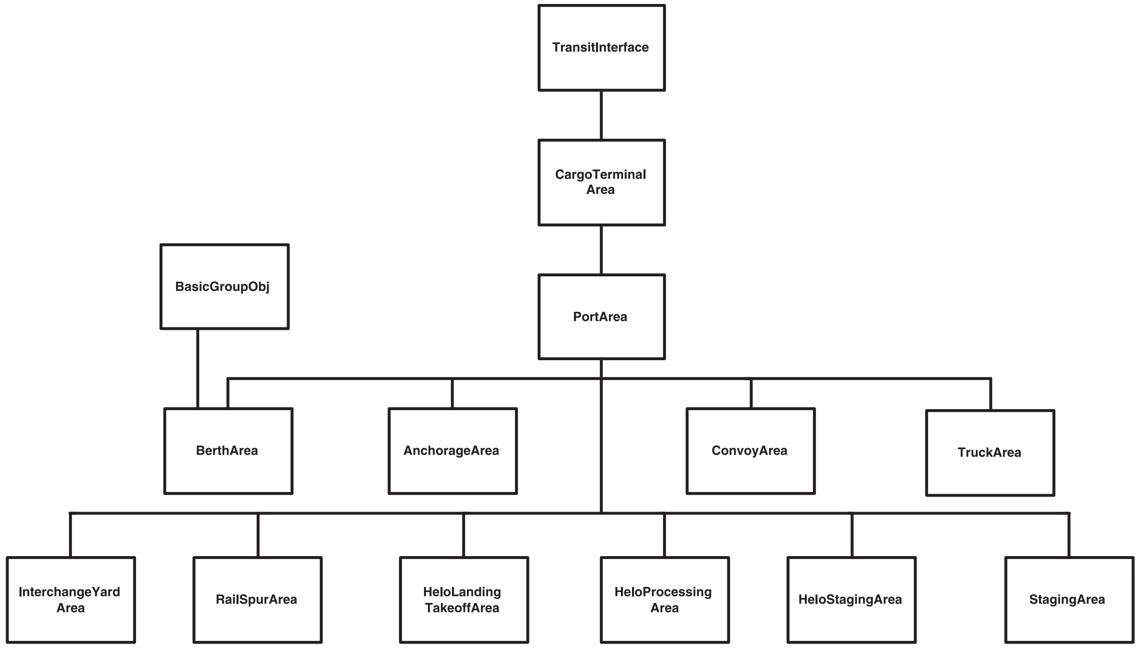

Figure 5. Port area objects.

There is one object of the appropriate type instantiated for each physical port area that is defined as being available for military use. These objects serve as the "containers" in which cargo items are processed and stored as the simulation executes.

4.2. Processes

A total of 88 processes are included in the simulation. These processes effect a state change for the individual cargo item being processed, the port area(s) in which it is being processed, and any resources that may be acting upon it. Each process is assigned a process time distribution to specify the time required to complete the process. Six distribution types supported by MODSIM III are made available to the user for each process. They are: triangular, exponential, uniform, normal, gamma, and beta distributions.

The cargo type, its physical characteristics, its transport, and the port configuration will define the ordered set of steps through which each cargo item must go. Some of these steps represent actual processes for which a time distribution is specified by the user and some are requests for resources or infrastructure to be assigned to the cargo. For example, a container arriving on a flatbed truck that will be handled with a CHE will always go through this defined set of steps processes. Steps annotated with a "*" indicate a process for which a process distribution time will be assigned and those annotated with a "#" indicate a step during which an undetermined amount of time can elapse waiting for port resources or infrastructure. Those steps without an annotation either occur instantaneously or spawn off a new time consuming activity for which time is accounted elsewhere.

1. Arrive at the port.
2. Assign a truck offloading area and wait for available space #.
3. Assign a container staging area and wait for available space #.
4. Assign a gate and lane and enter gate queue #.
5. Enter gate, be processed and pass through the gate *.
6. Transit to a truck offloading area *.
7. Enter truck offloading area and consume space.
8. Request and wait for port support activity (PSA) personnel #.

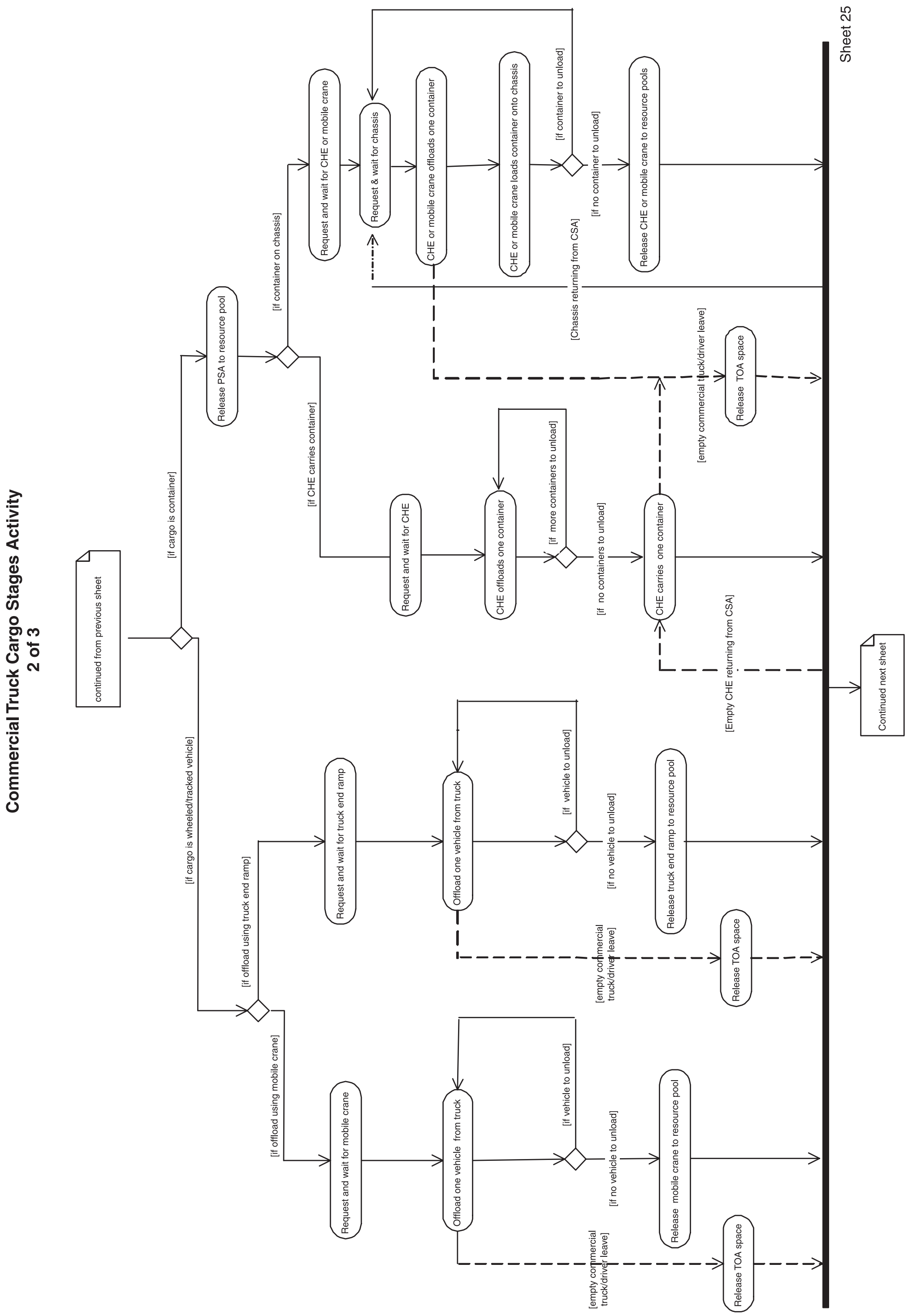

Figure 6. Commercial truck cargo stages activity.

9. Complete the receipt process *.
10. Release PSA personnel.
11. Request and wait for CHE #.
12. Offload container from truck *.
13. Release truck to exit port.
14. Transit to container staging area *.
15. Enter container staging area and consume space.
16. Park the container *.
17. Release the CHE.
18. Request and wait for PSA personnel #.
19. Complete the inspection process *.
20. Release PSA personnel.
21. Wait for the specified dwell time to elapse *.
22. Wait to be called forward to the berth #.
23. Request and wait for CHE #.
24. Transit to the berth *.
25. Offload container onto berth *.
26. Wait for berth crane #.
27. Be loaded onto the ship *.
28. Complete the lashing process on the ship *.

Figure 6 is a portion of the activity diagram that defines the commercial truck cargo stages activity.

The 28 steps listed above for containers on flatbeds processed with CHE would be distributed across a number of these activity diagrams.

The variability in the time required to process this piece of cargo will be affected by the availability of the port infrastructure (gate, truck offloading area, container staging area, berth) and the availability of port resources to support the activities (mobile crane or CHE, inspector, chassis, berth crane) as this piece of cargo competes against all other cargo items at the port being processed.

4.3 Resources

During the systematic analysis of PORTSIM 4.3 to verify its proper implementation, parameter sweeps for port resources would occasionally show counterintuitive results. The allocation of additional resources would sometimes lead to degraded port performance. It was discovered that the simplistic first-come, first-served approach to allocation of port resources often resulted in a feast or famine scenario. Some operations received all the resources requested while others would receive only a fraction of the resources requested. The total amount of work accomplished in the simulated port in a given time with the same amount of resources could actually fluctuate with different allocation schemes. However, the design of PORTSIM 4.3 was not sufficiently flexible to facilitate the implementation of alternate strategies. As a result, "what-if" scenarios to implement different allocation schemes were time consuming to implement and were impractical at best. The discovery of the potential negative impacts of an allocation scheme made it clear that the manual integration of results from a POE simulation run and a POD simulation run could not simply be accepted as accurate (especially when the allocation of resources is not specifically reported). The added complexity of additional port operations (POE and POD) competing for the limited resources needed an automated solution rather than a manual one. As a result, the need for an integrated port model became even more apparent.

The allocation scheme anomalies also pointed out that the model must allow for multiple allocation schemes to be implemented. At a real world port, a resource manager with years of experience, knowledge of port priorities, and knowledge of future workloads would rely on this experience and knowledge in making decisions. A simplistic approach would not be sufficient. PORTSIM 5 will have the flexibility to support multiple allocation schemes. Some schemes under consideration are the following:

- first-come, first-served global resource pools;
- first-come, first-served separate POE and POD resource pools;
- workload-based allocation smoothing;
- POE vs. POD priority schemes;
- port operation (train unloading vs. ship loading) priority schemes.

Allowing multiple allocation schemes and making the low-level allocation data available for analysis will help ensure that model results are not influenced by any modeling artifacts.

A total of 17 resource types are modeled in the simulation. These include transports that bring cargo into or out of the port (ships, trucks, locomotives, railcars), resources that move cargo within the port proper (tugs, helicopter tractors, chassis, CHE), equipment that loads/offloads cargo onto/from transports (truck end ramps, mobile cranes, berth cranes) and people (PSA personnel, harbor pilots, helicopter pilots, unit drivers, line handlers, and stevedores). Note that some resources such as container handling equipment (CHE) can serve multiple purposes: transport cargo within the port and load/unload cargo.

Resource pools are either defined for a specific port area type or are defined as global port resources. An example of each are line handlers at the berth and PSA personnel, respectively. A resource pool can either be shared by both POE and POD operations, or it can be allocated specifically to only one type of operation (and thus, two such resource pools must be defined if both POE and POD operations take place at the port area(s)). Depending on the options selected, the total number of resource pools supported during a simulation run can vary from 15 to 30. The request for a resource from a pool will wait until the total number of resources that has been requested can be supplied. Currently, all but helicopter tractors are allocated on a first-come, first-served basis. Helicopter tractors are distributed based on a priority system. Since the loading and offloading of helicopters is a time consuming process, the model will assign a higher priority to requests for a tractor that will keep the loading/offloading process moving while it will allow requests for a tractor to move a helicopter from reassembly to staging to delay.

4.4 INTERFACE

This section provides a brief description of the GUI for PORTSIM 5 and provides a few screen captures to show the general structure of the GUI and the steps that would be required to define and run a simulation. The GUI for PORTSIM 5 is written in Visual Basic 6.0. The steps to define a scenario and run a simulation are as follows:

- select a port and terminal;
- select type of port operation: (POE, POD, concurrent);
- for each of the port areas, enter attribute, resource, and process data as required;
- build routes between the various port areas and specify transit times;
- select the POE and/or POD force to move through the port;
- run the simulation.

Figure 7 is a screen capture of the top level configuration screen from which the user can access all scenario definition screens.

Figures 8–10 show attribute, resource and process time screens for anchorages.

On this screen, the user specifies whether the anchorage is to be used for: POE-only, POD-only, or concurrent operations, which of the available anchorages can be utilized, the types of ships that this anchorage can accept, and finally, the capacity of the anchorage.

On this screen, the user would specify whether the resources pools supporting the anchorage will be shared by POE and POD operations, the sizes of the tug and harbor pilot pools, and the number of tugs that would be assigned to each ship as it is moved to and from the berth.

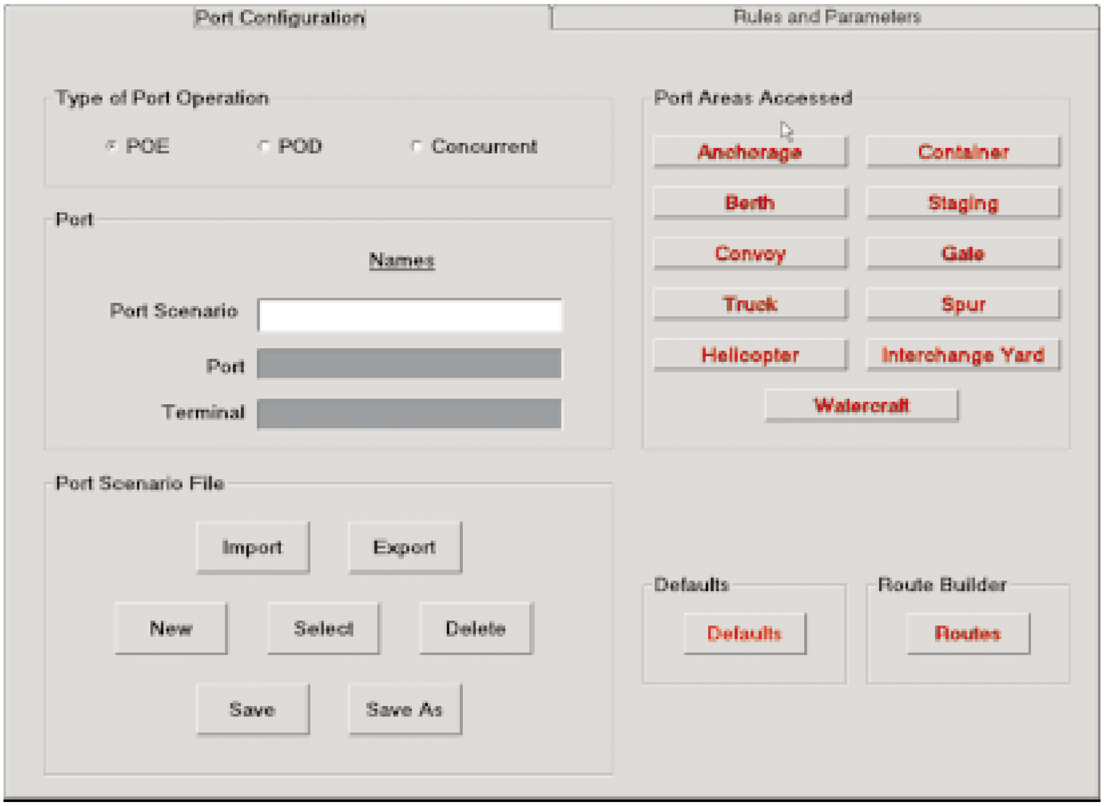

Figure 7. Port configuration screen.

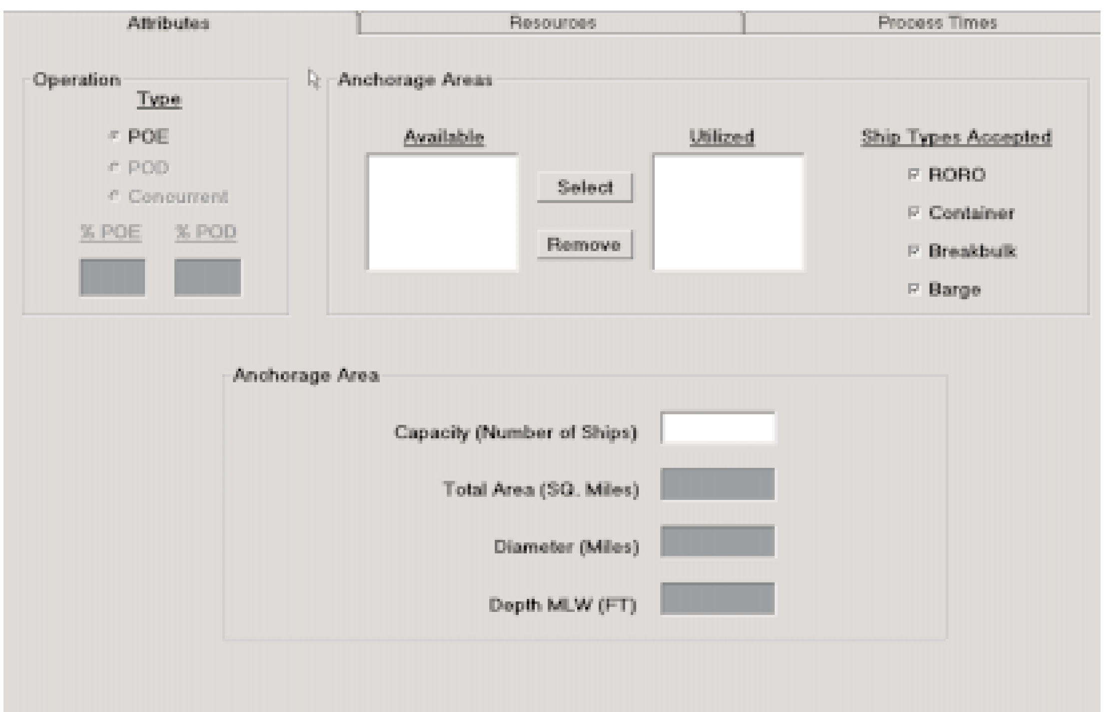

Figure 8. Anchorage attributes screen.

On this screen, the user specifies the types of distributions that will be made available to the user and the process times distributions associated with the anchorage areas. The default distributions limits the user to the default distribution type that has been assigned to this process.

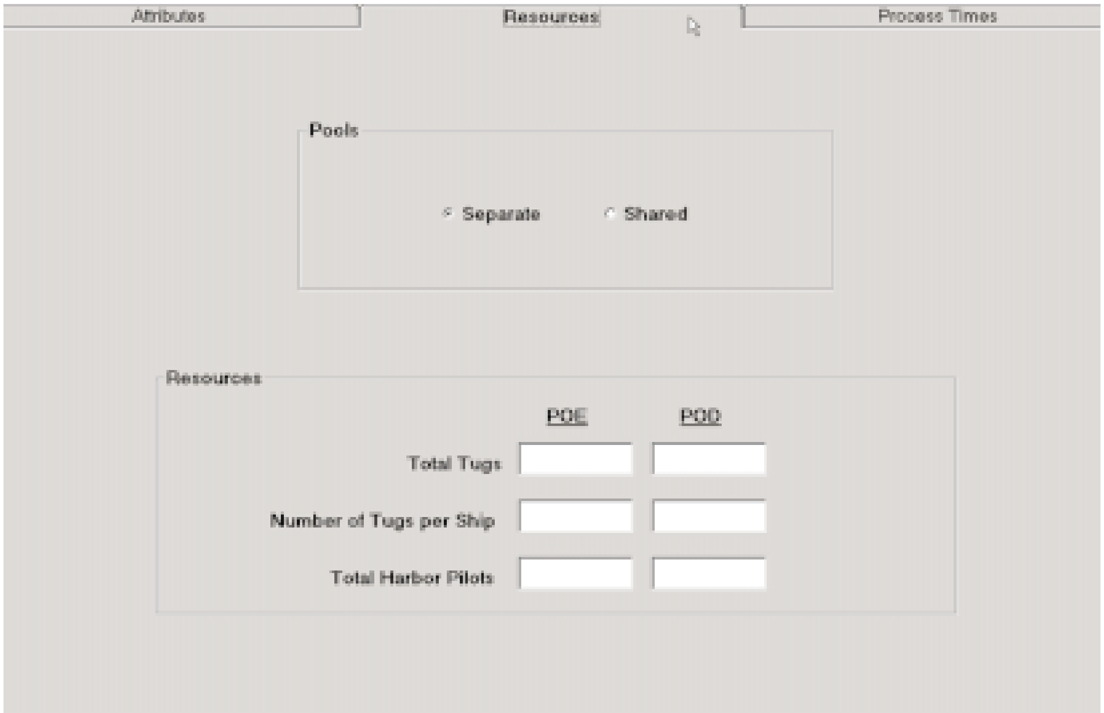

Figure 9. Anchorage resources screen.

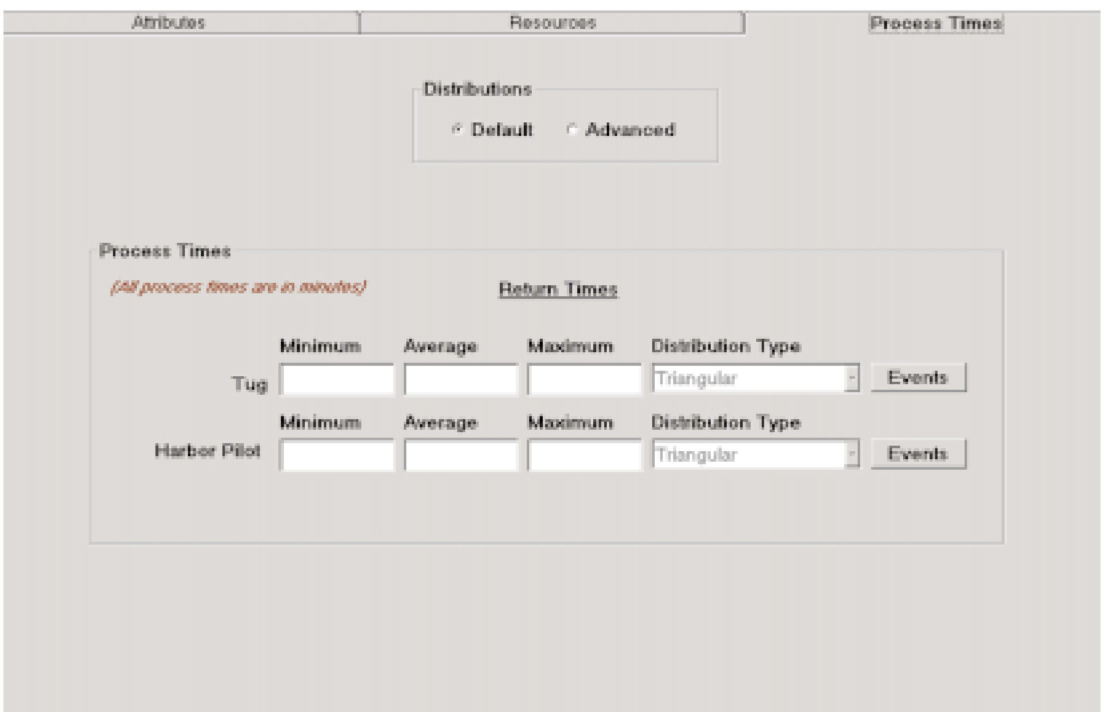

Figure 10. Anchorage process times screen.

In this example, both process time distribution types would be triangular. By clicking on the advanced radio button, the user has access to all six distribution types supported by the model.

This next section describes some of the outputs that PORTSIM 5 will generate. These three examples are prototyped graphs and reports.

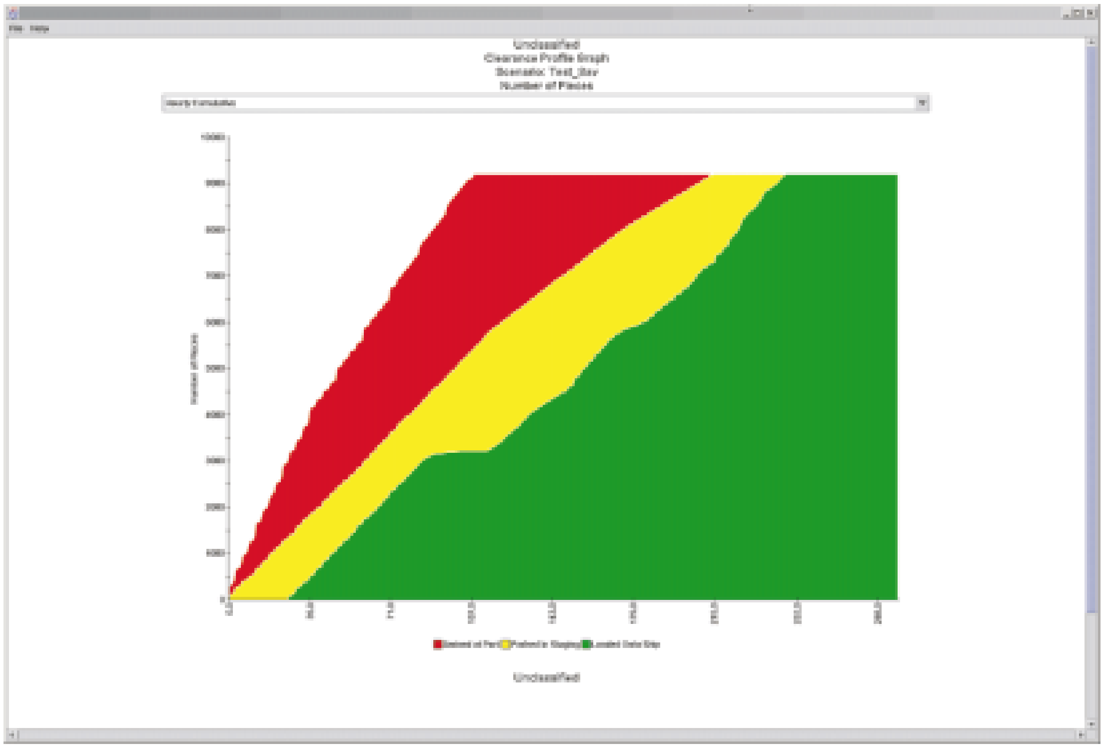

Figure 11. Clearance profile graph.

Figure 11 is a clearance profile graph that depicts the progress of the cargo items as they are processed through the port on their way to being loaded onto a ship. The red portion of the graph shows the cumulative total of the cargo arriving at the port. The yellow portion of the graph shows the cumulative total of cargo items that are parked in staging and ready to be loaded onto a ship. The difference in the slopes of the red and yellow portions indicates that the cargo items are arriving faster than they can be processed through to their ready-to-load state. From this graph, however, the user cannot determine if this condition is causing backlogs at various locations within the port. Finally, the green portion of the graph shows the cumulative total of cargo items that have been loaded onto a ship. This graph primarily shows how long a deployment would take to clear the port.

Figure 12 is a cargo report that shows the simulated time of major state changes for each individual cargo item: arrival at the port, cleared through the gate, parked in staging, available to load, and loaded onto a ship. This report can indicate that there may be insufficient port resources and/or infrastructure made available for use in the simulation. For example, significant time durations between arrival at port and cleared though gate can indicate insufficient gate allocation to the military operation (or inappropriately quick arrival of cargo at the port).

Figure 13 is a staging area utilization graph that depicts the hourly utilization of staging space. This graph can be used to determine if sufficient resources have been allocated for the deployment. A graph showing the achievement of 100% utilization of a resource cannot be interpreted as a necessarily good or bad situation. 100% utilization can indicate that an optimized allocation has been met. Or it can indicate that not enough resources have been allocated and the progress of the whole system is being slowed. Or the situation could exist that there is too much of a resource and that removing some of the resource will not affect the final outcome.

The ultimate goal for PORTSIM 5 is for it to become a key player in a transportation dommand (TRANSCOM) federation that will model end-to-end mobilization and deployment operations. The HLA data flows for the federation are enumerated below.

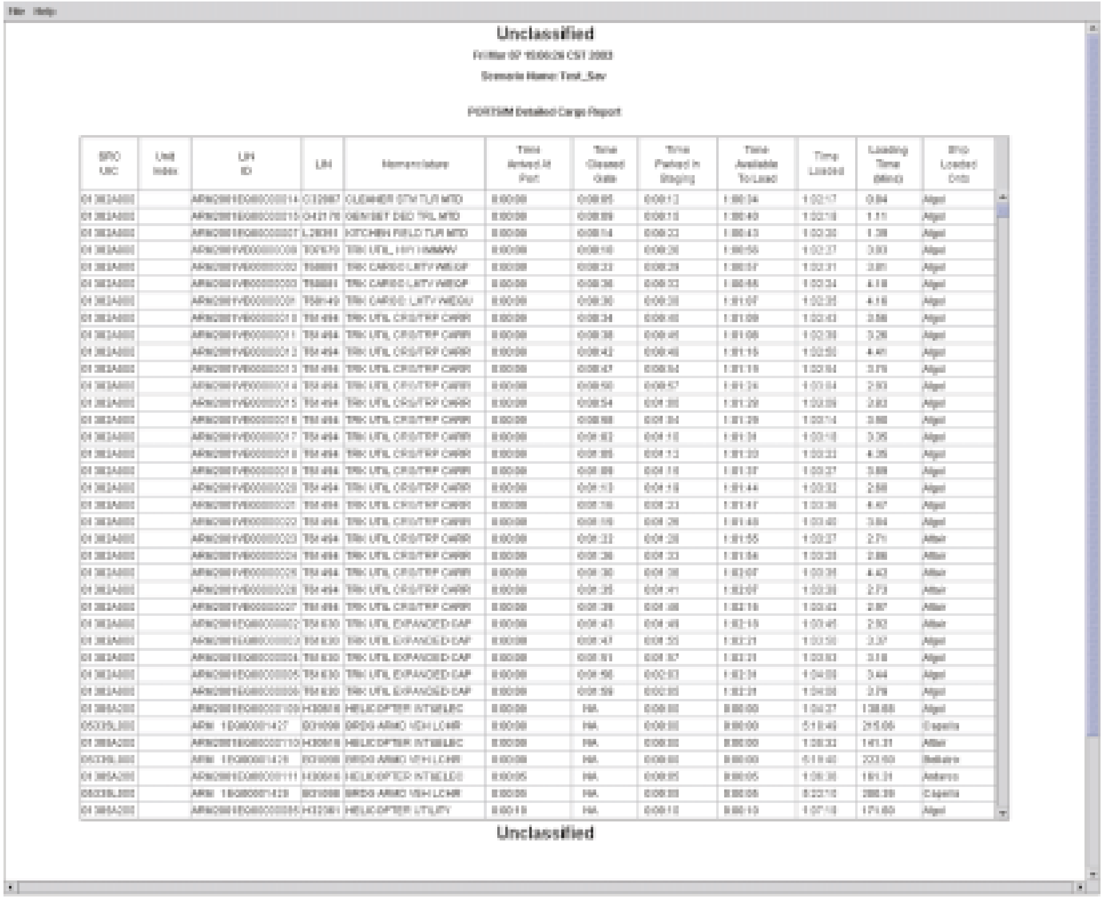

Figure 12. Cargo report.

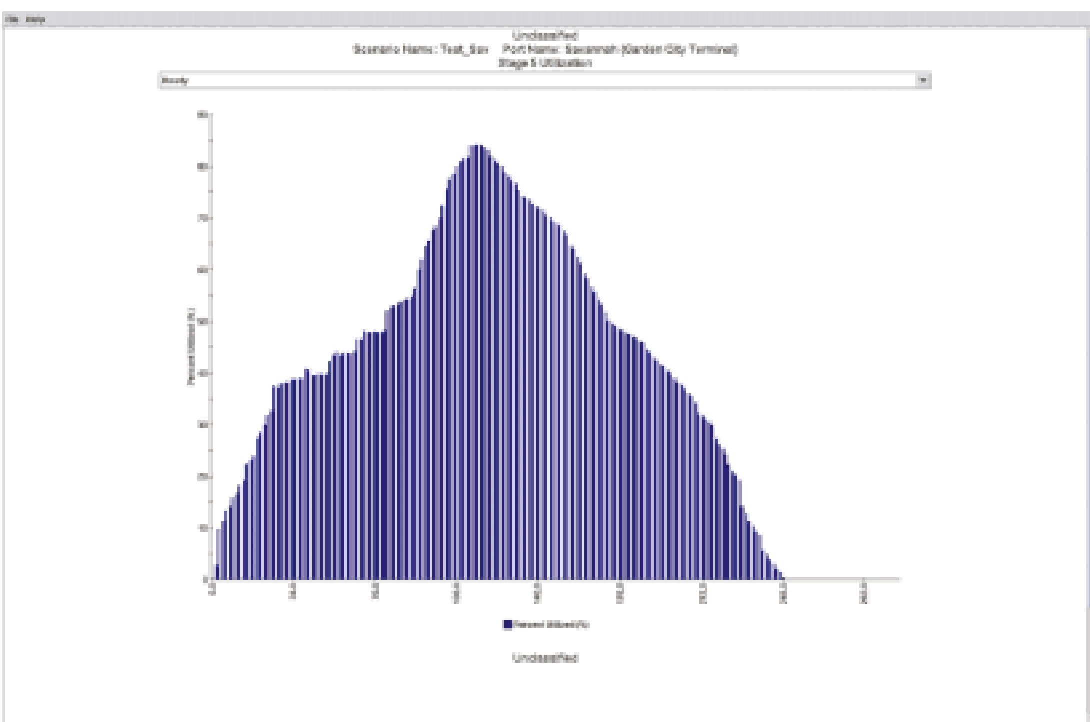

Figure 13. Staging area utilization graph.

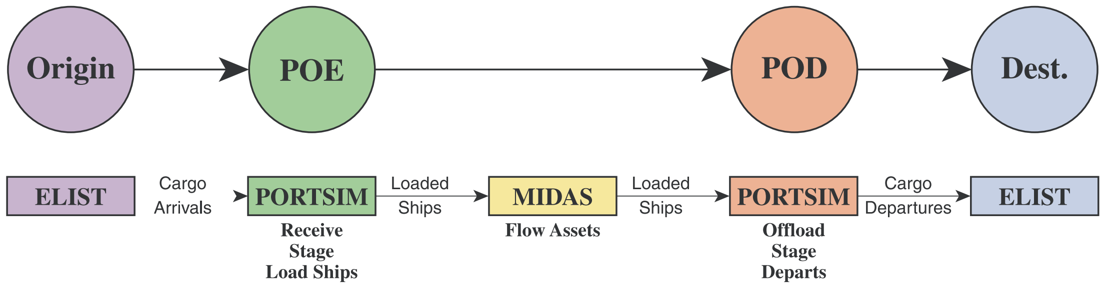

Figure 14. TRANSCOM federation overview.

- ELIST will flow forces from the fort to the POE and supply arrival information of all cargo and transports via HLA to PORTSIM.
- Using this information, PORTSIM will load the cargo onto the ships.
- The loaded ships will then be passed via HLA to MIDAS.
- MIDAS will move the ships along the strategic leg to the POD.
- MIDAS will feed this information via HLA to PORTSIM.
- PORTSIM will offload cargo from the ship and feed ELIST with cargo departure information via HLA.

Future enhancements will allow PORTSIM 5 to use these data feeds for virtually all scenario parameters.

Other goals and applications for PORTSIM 5 and beyond could include chemical and biological terrorism, weather impacts and labor unrest. For example, a chemical attack would constrain the availability of port areas, due to contamination cleanup time, and downgrade the overall labor resource as a function of the required protective measurements that need to be employed in such a situation. Overall port throughput would be expected to diminish. The estimated changes to system parameters could be computed external to the model and passed in via HLA.

The value of PORTSIM to the military has been ongoing and well documented. Much of PORTSIM's real world application is classified. Two general applications were "port workload" and "port regional readiness" studies done for the U.S. Army. PORTSIM also lends itself well to commercial port operations and could easily be adapted to model nonmilitary processes. For example, the modeling infrastructure could be used to represent grain loading and offloading or bulk loading of coal. A cost component could be developed to further enhance the model's appeal to the nonmilitary community.

The addition of spatial representation would further enhance the model, allowing port-specific data on travel times, distances and road capacities to impact the throughput and rate of closure. PORTSIM could also be enhanced to take advantage of the 2D and 3D visualization work currently under development at Argonne. Visualization provides an animated, graphical representation of a scenario run and gives a fast, accurate picture of cargo flow, highlighting bottlenecks, and underutilization of resources within the port.

5. CONCLUSION

The ability to accurately simulate throughput at a seaport remains a high priority for today's military. PORTSIM 5 builds on the existing body of work that has already been done in the logistics community and enhances the overall accuracy and dependability by modeling at the port level. Port-level modeling integrates POE and POD processes and provides for the system resource constraints that occur when simultaneous operations are necessary. PORTSIM 5 uses a set of conventions to handle resource allocation and improves the overall accuracy of throughput analysis.

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